

The Puzzling Compact Objects in Supernova Remnants

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Abstract. X-ray images of some young supernova remnants show bright point sources which have not been detected in radio, optical and gamma-ray bands. Despite the similarity of the X-ray spectra of these objects, they show a variety of temporal properties. Most likely, they are neutron stars whose properties (spin periods? magnetic fields? environments?) are different from those of radio and/or gamma-ray pulsars. We present an overview of observational results on several objects of this class — the central sources of Cassiopeia A, RX J0852–4622, RCW 103, Puppis A, and PKS 1209–51/52 — with emphasis on the recent *Chandra* observations.

1. Introduction

There are two types of isolated (non-binary) neutron stars (INSs) with quite different observational manifestations. *Active, rotation-powered pulsars* include, in addition to commonly known radio pulsars, some “radio-quiet” INSs whose radio pulsations are not seen because of unfavorably directed pulsar beams. Pulsar activity in these radio-quiet active pulsars can be seen at wavelengths other than radio (e.g., in γ -rays — the classical example is Geminga), and it can manifest itself, in young pulsars, through a compact pulsar-wind nebula (PWN). A distinctive feature of active pulsars is that these objects are powerful sources of *nonthermal radiation from NS magnetospheres*, in radio through γ -rays. The intensity of this nonthermal radiation usually exceeds that of the surface (thermal) radiation, at least in young pulsars.

Recent observations have established that there exist isolated compact objects, presumably INSs, which show no signs of pulsar activity — i.e., the usual pulsar processes, which result in beams of relativistic particles, PWNe, and strong nonthermal radiation, do not operate in these objects. They are often called *radio-silent INSs* (or INS candidates), *failed pulsars*, *dead pulsars*, etc — none of these terms describes their properties adequately (e.g., some of these objects do show X-ray pulsations, but their origin is apparently quite different from that observed from ‘ordinary’ pulsars). These objects can be further divided in at least four classes, based on their observational manifestations. First, six of them have been dubbed *Anomalous X-ray Pulsars* (AXPs; Mereghetti &

Stella 1995; van Paradijs, Taam, & van den Heuvel 1995) because they resemble accreting binary pulsars, but their luminosities, $L_x \sim 10^{35}$ erg s $^{-1}$, are two-three orders of magnitude lower, their spectra are considerably softer than those of binary pulsars, and their periods cluster in a narrow range of 6–12 s (Israel, Mereghetti, & Stella 2001). The second class is comprised of three (perhaps, four) *Soft Gamma-ray Repeaters* (SGRs; Kouveliotou 1995) whose quiescent radiation shows many similarities with AXPs, but, contrary to AXPs, SGRs occasionally undergo strong outbursts, with peak luminosities up to 10^{44} erg s $^{-1}$. Thompson & Duncan (1996) suggested that AXPs and SGRs are *magnetars* — INs with superstrong magnetic fields, $\sim 10^{14}$ – 10^{15} G. Some of the AXPs and SGRs are apparently associated with supernova remnants (SNRs). Recent results on AXPs and SGRs are presented by S. Kulkarni (this volume). One more class of presumably older “*truly isolated*” (i.e., not associated with SNRs), radio-silent NSs has emerged recently (e.g., Treves et al. 2000). These objects show very soft, thermal-like X-ray radiation with temperatures $kT \sim 50$ – 150 eV and luminosities $\sim 10^{32}$ – 10^{33} erg s $^{-1}$. Finally, *Compact Central Objects* (CCOs) have been found in several SNRs, which have not been identified as active pulsars, AXPs or SGRs. These objects are particularly puzzling. Below we will discuss recent results on five CCOs which have been observed with the *Chandra* X-ray Observatory.

2. Observational Results

2.1. General Overview

Observational properties of CCOs are summarized in Tables 1 through 5. First column of Table 1 gives the positions for the four objects observed with *Chandra* in an imaging mode (accurate to $1''$ – $2''$) and the most accurate *ROSAT* HRI position (uncertainty $\sim 5''$) for the fifth source. In the other columns, the host SNRs, with their ages and distances, are listed. The references here and in the other tables are given only to recent works, where the references to earlier results can be found.

Object	SNR	Age kyr	d kpc	Ref.
CXO J232327.9+584843	Cas A	0.32	3.4(3.3–3.7)	1
CXO J085201.4–461753	G266.1–1.2	~ 1 –3	1(1–2)	2
CXO J161736.3–510225	RCW 103	1–3	3.3(3–7)	3
CXO J082157.5–430017	Pup A	1–3	2.2(1.6–3.3)	4
RX J121000.8–522625	G296.5+10.0	3–20	2.1(1.3–3.9)	5

Table 1. Compact Central Objects in SNRs. References: 1- Murray et al. (2001); 2- Pavlov et al. (2001); 3- Garmire et al. (2000a), Leibowitz & Danziger (1983); 4- Zavlin et al. (1999), this work; 5- Zavlin et al. (1998).

Table 2 gives the periods P (detected or suspected — the latters are marked with ‘[?]’), the observed X-ray fluxes F_x (in units of 10^{-12} erg cm $^{-2}$ s $^{-1}$) in

energy bands ΔE , and limiting optical/IR magnitudes for the same five CCOs (abbreviated positions in first column). We see that the CCOs are X-ray bright — in fact, three of them, the CCOs of RCW 103, Pup A and G296.5+10.0, were discovered with *Einstein*, and the Cas A CCO was found in the archival *Einstein* data. On the other hand, no optical, radio or γ -ray counterparts have been identified for these objects, except perhaps the RCW 103 CCO (see below). The fluxes of four CCOs have not shown long-term variabilities, but the RCW 103 CCO is clearly variable (Gotthelf, Petre, & Vasisht 1999) — we present the lowest and highest flux values observed with *Chandra*.

Object	P	$F_{x,-12}$	ΔE keV	Optical/IR mag	Ref.
J2323+5848	12ms[?]	0.8	0.3–6	R>27.8, m ₆₇₅ >28.9 J>22.5, K _s >21.2	1
J0852–4617	...	1.4	0.4–6	B>22.5, R>21.0	2
J1617–5102	6hr[?]	0.9–60	0.5–9	J \approx 22.3, H \approx 19.6, K _s \approx 18.5 [?]	3
J0821–4300	...	4.5	0.4–6	r' >24.8, i' > 24.4, z' >22.4	4
J1210–5226	424ms	1.9	0.5–6	r' >24.8, i' > 24.4, z' >22.9	5

Table 2. Periods, X-ray fluxes, and optical/IR magnitudes. References: 1- Murray et al. (2001), Pavlov et al. (2000), Kaplan et al. (2001), Fesen et al. (this volume); 2- Pavlov et al. (2001), this work; 3- Garmire et al. (2000b), this work, Sanwal et al. (2002); 4- this work, Wang & Chakrabarty (this volume); 5- Zavlin et al. (2000), this work, Wang & Chakrabarty (this volume).

Table 3 gives the results of fits of the *Chandra* ACIS spectra with the ‘standard’ blackbody (BB) and power-law (PL) models. The bolometric luminosities L_{bol} for the BB fits, and the luminosities L_x for the PL fits in the bands ΔE from Table 2, are in units of 10^{33} erg s $^{-1}$. The luminosities and the effective radii R are for most plausible distances (see Table 1). The parameter γ is the photon index. The hydrogen column densities are in units of 10^{22} cm $^{-2}$. In

Object	kT keV	R km	$L_{\text{bol},33}$	$n_{\text{H},22}$	γ	$L_{x,33}$	$n_{\text{H},22}$	Ref.
J2323+5848	0.49	0.5	1.6	1.1	4.1	500	2.2	1
J0852–4617	0.40	0.3	0.3	0.4	2
J1617–5102	0.4–0.6	0.2–1.6	0.5–30	1.5	4–5	10–600	3.7	3
J0821–4300	0.38	1.4	4.2	0.2	4.8	80	1.0	4
J1210–5226	0.25	1.6	1.3	0.04	5.1	8	0.5	5

Table 3. Best-fit fit parameters for blackbody and power-law fits. References: 1- Murray et al. (2001); 2- this work; 3- Garmire et al. (2002); 4,5- this work.

some cases, the ‘standard’ models do not fit the observed spectra well — e.g., the recently observed *Chandra* ACIS spectrum of the G266.1–1.2 CCO is too

steep at higher energies to fit a PL model. The fits with the simple BB model are formally acceptable for most CCOs. They give temperatures in a narrow range of 0.3–0.6 keV, but the effective radii, 0.2–1.6 km, are much smaller than the expected NS radii, $R_{\text{NS}} \approx 10\text{--}15$ km. On the other hand, the PL spectra (where they fit the data) are very steep (in comparison with typical $\gamma \approx 1.5\text{--}2$ measured for active radio pulsars), and the PL fits yield too high values of n_{H} . It is quite plausible that none of these simplistic fits provide true physical parameters of the sources. Therefore, we also present, in Table 4, the fits with the magnetic NS hydrogen atmosphere models (Pavlov et al. 1995) which generally give lower effective temperatures and larger emitting areas than the BB fits. In the case of two of the five CCOs (in Pup A and G296.5+10.0), the radii become close to the expected NS radii, but they are still too small for the other three CCOs.

Object	kT_{eff}^{∞} keV	R^{∞} km	L_{bol}^{∞} $10^{33} \text{ erg s}^{-1}$	n_{H} 10^{22} cm^{-2}	Ref.
J2323+5848	0.3	1	2	0.8	1
J0852–4617	0.27	1.5	0.8	0.5	2
J1617–5102	0.3	1–8	1–60	1.7	3
J0821–4300	0.17	10	8	0.4	4
J1210–5226	0.14	11	1	0.2	5

Table 4. Fits with magnetic hydrogen atmosphere models. The subscript $^{\infty}$ denotes the values as seen by a distant observer. References: 1- Pavlov et al. 2000; 2,3,4,5- this work.

For comparison with the AXP and SGR quiescent spectra, which are well described by a two-component BB+PL spectral model, we also present, in Table 5, the PL+BB fits for three CCOs (the PL component is unconstrained for the two other CCOs). As a rule, the additional PL component (20%–30% of the observed energy flux) only slightly improves the quality of the fits.

Object	kT keV	R km	γ	$n_{\text{H},22}$	$F_{\text{x}}^{\text{bb}}/F_{\text{x}}^{\text{pl}}$	Ref.
J2323+5848	0.45	0.54	1.7	[1.1]	3.8	1
J1617–5102	0.52	1.5	3.8	2.2	2.2	3
J1210–5226	0.22	2.0	3.6	0.13	3.0	5

Table 5. Best-fit fit parameters for BB+PL fits. The hydrogen column density was fixed in the J2323+5848 fit. The fit for J1617–5102 is for 2001 Oct 7 data. References: 1- Murray et al. (2001); 3,5- this work.

2.2. Individual Sources

Cas A CCO: The central source of Cas A, the youngest Galactic SNR, was discovered in the first-light *Chandra* observation (Tananbaum 1999) and after that found in the archival *ROSAT* and *Einstein* images (Aschenbach 1999; Pavlov &

Zavlin 1999). The *Chandra* observations of this source were analyzed by Pavlov et al. (2000), Chakrabarty et al. (2001), and Murray et al. (2001). The source is about $7''$ from the Cas A expansion center (Thorstensen et al. 2001), which corresponds to the transverse velocity of $\simeq 330$ km/s, for the age of 320 yrs and distance of 3.4 kpc. Deep searches in the radio (McLaughlin et al. 2001) and optical/IR (Kaplan, Kulkarni, & Murray 2001; Fesen, Chevalier, & Holt, this volume) failed to find a counterpart. The very large X-ray-to-optical flux ratios (e.g., $F_x/F_R > 3000$), together with the proximity to the SNR expansion center, prove that the point source is the compact remnant of the SN explosion. A lack of a PWN around the source, the steep X-ray spectrum, and low luminosity argue that it is not an active, rotation-powered pulsar. The very high BB temperature and the very small size hint that the radiation emerges from small heated regions on the NS surface. If even the NS surface were covered with a light-element (H or He) atmosphere, the effective temperature would still be too high for a cooling NS of this age, and the size would be smaller than the NS radius. The origin of the heated regions on the NS surface remains unclear. In principle, they could be explained by a very strong magnetic field localized in a small region close to the surface, which would locally increase the surface temperature due to enhanced thermal conduction along the magnetic field, or due to heat caused by field decay. This hypothesis, however, has not been supported by direct calculations. The temperature nonuniformity might be also associated with a nonuniform chemical composition of the crust/atmosphere — for instance, light-element polar caps, formed by accretion onto the magnetic poles of the nascent NS, would be hotter than the rest of the surface comprised of heavy elements (e.g., iron) because the low-Z envelopes are more efficient heat conductors. However, it is not clear whether such a gradient of chemical composition could survive for a long time, or what would be the mechanism supporting this gradient if there is no accretion at the present stage.

If the CCO radiation is emitted from small heated regions on the NS surface, then it would be natural to expect that the radiation is pulsed. The deepest search for pulsation, undertaken by Murray et al. (2001), resulted in a candidate period of about 12 ms, whose significance, however, is rather low. Such a period would not be easy to explain. On one hand, it strongly limits the magnetic field — a NS rotating with such a period should be an active pulsar at $B \gtrsim 10^9$ G, but we see no manifestations of pulsar activity. On the other hand, if the magnetic field is low enough to put the NS under the ‘pulsar death line’, it would be very difficult to explain the origin of the heated regions.

One could assume that the observed X-ray emission is caused by accretion onto a NS or a black hole (BH), with an accretion rate $\dot{M} \sim 10^{12}$ g s $^{-1}$. Although this rate is very low compared to that in accreting compact objects in binaries, it is, nevertheless, too high to be explained by accretion from the circumstellar medium because a very high density of the ambient matter, $n \gtrsim 10^5 (v/300 \text{ km/s})^3 \text{ cm}^{-3}$, would be required. We cannot completely rule out the possibility of accretion from a very underluminous (e.g., $M_R > 11$) secondary companion, but it would be much dimmer than secondaries in usual low-mass X-ray binaries. Somewhat more plausible source of accretion might be a ‘fossil disk’, left-over after the SN explosion (van Paradijs et al. 1995), but such a disk should be much less luminous in the optical than those detected in

X-ray binaries. Generally, any accretion model seems to contradict to the lack of variability of the X-ray radiation.

To conclude, there is no full understanding of the real nature of the Cas A CCO. In our opinion, most likely it is an INS emitting thermal radiation from small heated surface areas. Critical observations would be a firm detection of X-ray pulsations and deep IR observations.

CCO in “Vela Junior”: The shell-like SNR G266.1–1.2 (= RX J0852–4622) has been discovered quite recently with *ROSAT* at the south-east corner of the Vela SNR (Aschenbach 1998). Possible detection of the 1.156 MeV γ -ray line of the radioactive isotope ^{44}Ti with the *CGRO* COMPTEL (Iyudin et al. 1998) may imply a very young age, ~ 700 yr, at a distance of ~ 200 pc, although further observations of the SNR have shown that it is likely older and more distant (Slane et al. 2001). There were a few reports about possible point-like X-ray sources close to the SNR center (Aschenbach 1998; Slane et al. 2001; Mereghetti 2001), but it had been hard to rule out the association of the CCO candidates with two bright stars in the field. A 3-ks observation with the *Chandra* ACIS allowed us (Pavlov et al. 2001; Kiziltan et al., this volume) to firmly detect the point source and measure its position with high accuracy (see Table 1). A follow-up optical observation showed a star (B=18.9, R=16.9) at $2''.4$ from the center of the *Chandra* error circle, but the association of this star with the CCO looks unlikely. The limiting magnitudes of an optical counterpart (Table 2) are not as deep as for the other CCOs, but the X-ray-to-optical flux ratio is high enough to conclude that this is indeed the compact remnant of the SN explosion, at $\approx 4'$ from the SNR center. A follow-up 30-ks *Chandra* ACIS observation allowed us to measure the source flux and the spectrum. Interestingly, the spectrum does not fit the PL model, but it fits the BB model and shows a temperature slightly below that of the Cas A CCO. The size of the emitting area and the luminosity cannot be accurately estimated because of the poorly known distance (the values in Table 3 are normalized to $d = 1$ kpc); at a plausible distance of 2 kpc the size and the luminosity are close to those of the Cas A CCO. These similarities suggest that the Cas A and Vela Junior CCOs indeed belong to the same family.

The second *Chandra* ACIS observation was carried out in Continuous Clocking (CC) mode, which allowed us to search for pulsations. A candidate period, $P = 301$ ms, was found at a 2.8σ level — too low significance to claim it is real until it is confirmed by another observation.

RCW 103 CCO: Historically, it was the first radio-quiet, X-ray-bright NS candidate found in a young SNR (Tuohy & Garmire 1980). It has been studied with *Einstein* (Tuohy et al. 1983), *ASCA* (Gotthelf, Petre, & Hwang 1997) and *Chandra* (Garmire et al. 1999, 2000ab). Contrary to the other CCOs, strong (up to a factor of 70) long-term variations of its flux have been found. First 16-ks *Chandra* ACIS observation (1999 September 26) of this source showed a light curve which looked like a fraction of a sinusoid with a period of about 6 hr; a similar period was apparently found in the archival *ASCA* data (Garmire et al. 2000a). In second 23-ks *Chandra* ACIS observation of 2000 February 8 (Garmire et al. 2000b), the source was so bright that it was difficult to measure its properties because of strong pile-up (saturation) of the source image. The source was certainly variable, at a 20% level, during this observation, but the variability did

not look periodic. Further long X-ray observations will show whether the 6-hr period is observable in the low state only. A series of six short, 3–4 ks, *Chandra* ACIS observations of the CCO in January–October 2001 showed that the source was in high state during this period (flux around 1×10^{-11} erg cm $^{-2}$ s $^{-1}$ in the 0.5–9 keV band). In most of the *Chandra* observations, the source spectrum resembled a blackbody; its temperature $kT \approx 0.4$ – 0.6 keV did not show correlations with the flux, while the effective emitting area was approximately proportional to the flux, with a maximal size of ≈ 1.6 km in the high state. Fits with the hydrogen NS atmosphere models give, as usual, lower temperatures and larger sizes, but even the increased effective radius remains smaller than R_{NS} , at least in low state. Adding a PL component slightly improved the fits for some of the observations, but it was poorly constrained in most cases.

The last of the short *Chandra* ACIS observations (2001 October 7) was taken in CC mode, which allowed for the first search of fast pulsations. An upper limit on pulsed fraction in a 0.03–300 s period range is $f_p < 15\%$.

A number of attempts to detect an optical/IR counterpart have been undertaken. The deepest observations (2001 May–July, with VLT, in the I,J,H,Ks bands) has shown a very red object at $1''.6$ from the center of the *Chandra* error circle. Its IR magnitudes (uncertainties of the values in Table 2 are ± 0.5 mag) correspond to $M_J=8.4$, $M_H=6.2$, $M_{Ks}=5.4$ at $d = 3.3$ kpc, $A_V = 4.7$. We do not exclude the possibility that this is a dwarf companion or the long-sought fossil disk (in the former case, the 6-hr period, apparently seen in the low state, could be a binary period), but a more accurate astrometric and photometric analysis is required to confirm the identification.

To summarize, the central source of RCW 103 is the only strongly variable CCO. The most natural explanation for the variability is accretion with a variable rate, $\dot{M} \sim 10^{12}$ – 10^{14} g s $^{-1}$. The source of accretion, a low-luminosity companion in a binary system or a dim disk, can be established from further IR observations. If the IR counterpart is confirmed, this will be the first discovery of either a very young binary system with a compact companion in a SNR or a fossil disk which is still present after the SN explosion about 2 kyr ago.

Pup A CCO: This object, at about $6'$ from the kinematical center of the SNR, was discovered with *Einstein* (Petre et al. 1982) and further studied with *ROSAT* and *ASCA* (Petre, Becker, & Winkler 1996; Zavlin, Trümper, & Pavlov 1999). Large values of F_x/F_{opt} (see Table 2) suggest that this is a NS or a BH. The pre-*Chandra* X-ray observations have shown that, similar to other CCOs, the spectrum of this object is either a very steep power law or, more likely, thermal-like, with a BB radius substantially smaller than R_{NS} . The radius becomes compatible with R_{NS} , and the effective temperature consistent with ‘standard’ NS cooling models (see Table 4), if one fits the spectra with a hydrogen atmosphere model with $B > 6 \times 10^{12}$ G (Zavlin et al. 1999). The source was observed with *Chandra* ACIS in 2000 January 1 (12 ks). The spectral parameters obtained from this observation are consistent with those obtained with *ROSAT* and *ASCA*.

Observations of this CCO with the *Chandra* HRC (1999 December 21 and 2001 January 25, 18 ks each) allowed us to obtain high-resolution images and search for pulsations. We found no signs of a PWN around the source — an additional confirmation that this is not an active pulsar. These observations did

not confirm a 75-ms candidate period reported by Pavlov, Zavlin, & Trümper (1998) at a 3σ level. (This result is not surprising because, with the period and its derivative suggested by Pavlov et al. 1998, the source should be an active pulsar, in contradiction with its observed properties.) Moreover, no other periods are seen in the power spectra, with an upper limit on pulsed fraction $f_p < 10\%$ in a 0.003–300 s period range.

CCO in PKS 1209–51/52: The oldest CCO in our sample was discovered with *Einstein* (Helfand & Becker 1984) 6' off-center the 81' diameter shell SNR G296.5+10.0. *EXOSAT*, *ROSAT* and *ASCA* observations (Kellet et al. 1987; Mereghetti, Bignami, & Caraveo 1996; Vasisht et al. 1997; Zavlin, Pavlov, & Trümper 1998) have established its spectral characteristics similar to those of the Pup A CCO, albeit with lower temperatures inferred from thermal fits. Zavlin et al. (1998) have shown that fitting the CCO spectra with the magnetic hydrogen atmosphere model yields a radius close to the expected NS radius, an effective temperature consistent with the standard NS cooling models, and a hydrogen column density compatible with the values obtained from independent measurements.

This object was observed with *Chandra* ACIS on 2000 January 6 (30 ks) in CC mode. Timing analysis allowed us to find a strong (5σ) candidate for the period, $P = 0.42412924\text{ s} \pm 0.23\mu\text{s}$ (Zavlin et al. 2000). The pulsations are smooth, with one peak per period and pulsed fraction $f_p = 9\% \pm 2\%$. We can speculate that the pulsations may be caused by temperature nonuniformity due to anisotropic heat conduction in a strong magnetic field. To estimate the magnetic field and elucidate the nature of this INS, the period derivative must be measured.

Fits of the *Chandra* spectra with continuum spectral models give fitting parameters very close to those obtained in the pre-*Chandra* observations, but the quality of the fits is worse now because of an apparent broad spectral feature, presumably caused by inaccuracy of CCD response. Thus, the *Chandra* ACIS spectrum of this source does not contradict to the suggestion of Zavlin et al. (1998) that this is a NS covered with a strongly magnetized hydrogen atmosphere.

3. Summary

Although some properties of CCOs (in particular, their spectra) are very similar to each other, this still does not guarantee that they represent a uniform class of objects. The most outstanding among these sources is the RCW 103 CCO, with its highly variable flux (time scales hours to months), putative 6-hr period, and a possible IR counterpart. We presume that this source is not a truly isolated NS (i.e., it is powered by accretion, at least in its high state), although it is not a rotation-powered active pulsar. The other four CCOs have shown neither long-term variabilities nor indications of binarity. If we adopt a plausible hypothesis that their radiation is thermal and assume that it is adequately described by the same spectral model (e.g., BB or H atmosphere) for each of the sources, then we have to conclude that the emitting area is growing with the CCO's age. If we assume that the radiation emerges from a hydrogen atmosphere, then the size is

consistent with a NS radius for the two oldest CCOs, being smaller for the two younger ones. One might suggest that the two younger and two older CCOs are objects of different types, but it does not answer the fundamental question: *Why are the emitting regions of at least two young CCOs so small?* If this is due to the above-discussed nonuniformities of magnetic field or chemical composition, one could speculate that these nonuniformities are formed at very early stages of the NS life, and they weaken (spread over the NS surface) in a time of several thousand years. One could assume that the two younger CCOs are BHs, not NSs, but then we would have to invoke accretion as an energy source, which does not look consistent with a lack of variability.

The key property to understand the nature of CCOs is their periodicity. So far, the period has been found with high significance (albeit in only one observation) only for the oldest of the CCOs, and its value of 424 ms proves that at least this CCO is a NS. The suspected 12 ms period of the youngest CCO is very puzzling — we have to wait for its confirmation before making definitive conclusions on the nature of this source.

Another intriguing question is whether the CCOs are close relatives of AXPs and SGRs, as one could assume based on similarity of their spectra. Based on the above-mentioned CCO periods (which, however, require confirmation), the formal answer should be ‘no’ rather than ‘yes’. On the other hand, it is hard to explain why the apparent temperatures and sizes of emitting regions would be so similar in objects of different nature. Therefore, we do not rule out the possibility that at least some of the CCOs belong to the same family as AXPs and/or SGRs, perhaps at different stages of their evolution. In this respect, it would be particularly interesting not only to confirm/measure the CCO periods, but also to evaluate the period derivatives.

To conclude, with the aid of the *Chandra* observations two more CCOs have been discovered, data of much better quality were obtained, and the main problems were formulated more clearly. We expect these problems to be resolved by further observations — X-ray timing and spectroscopy, supplemented with deep NIR imaging.

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